4,000 Spectra or 4,000,000 ROIs per Second: EPICS Support for High-Speed Digital X-ray Spectroscopy with the XIA xMap

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Outline

- Overview of EPICS Interface to XIA DXP electronics for x-ray fluorescence detectors
- New features in dxp R3-0; support for high-speed mapping with xMAP module
- First results with xMAP from GSECARS 13-ID beamline at APS

Acknowledgments

- Ulrik Pederson (Diamond) for initial version of xMAP mapping mode support

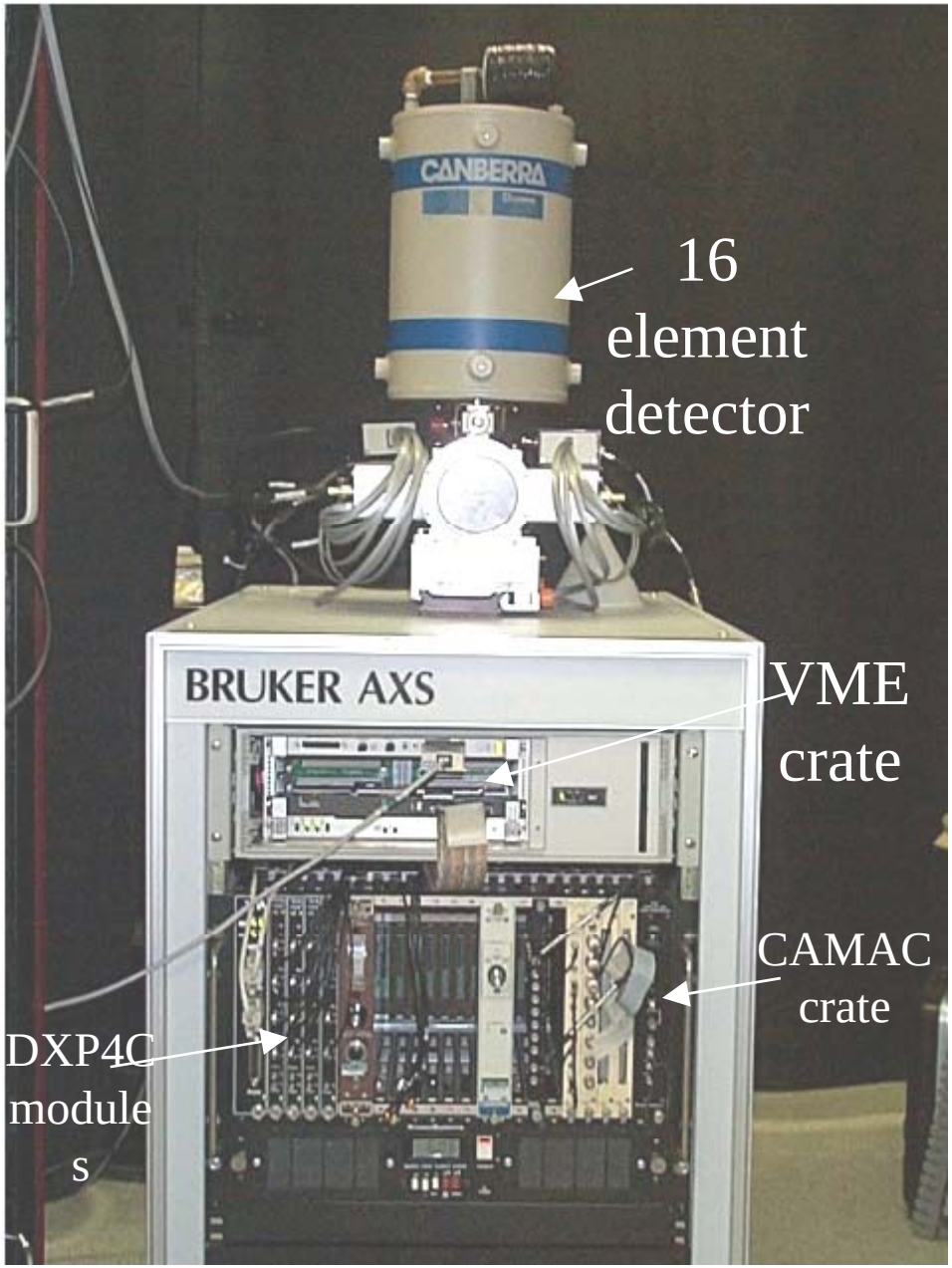
- Matt Newville (GSECARS) for the data, collected using his Python higher-level software

Motivation

- Need a cost-effective way to collect XRF spectra from multi-element detector arrays
- Modern detectors, particularly silicon drift diodes (SDD) can run at >250,000 cps per detector, or >1,000,000 cps for a 4-element array like the quad Vortex
- Depending on the application, can thus get a usable signal (1,000 counts) in 1 ms.
  - Need to keep the overhead less than that!

XIA Fast DSP Electronics for X-ray Fluorescence Detectors 4 Models

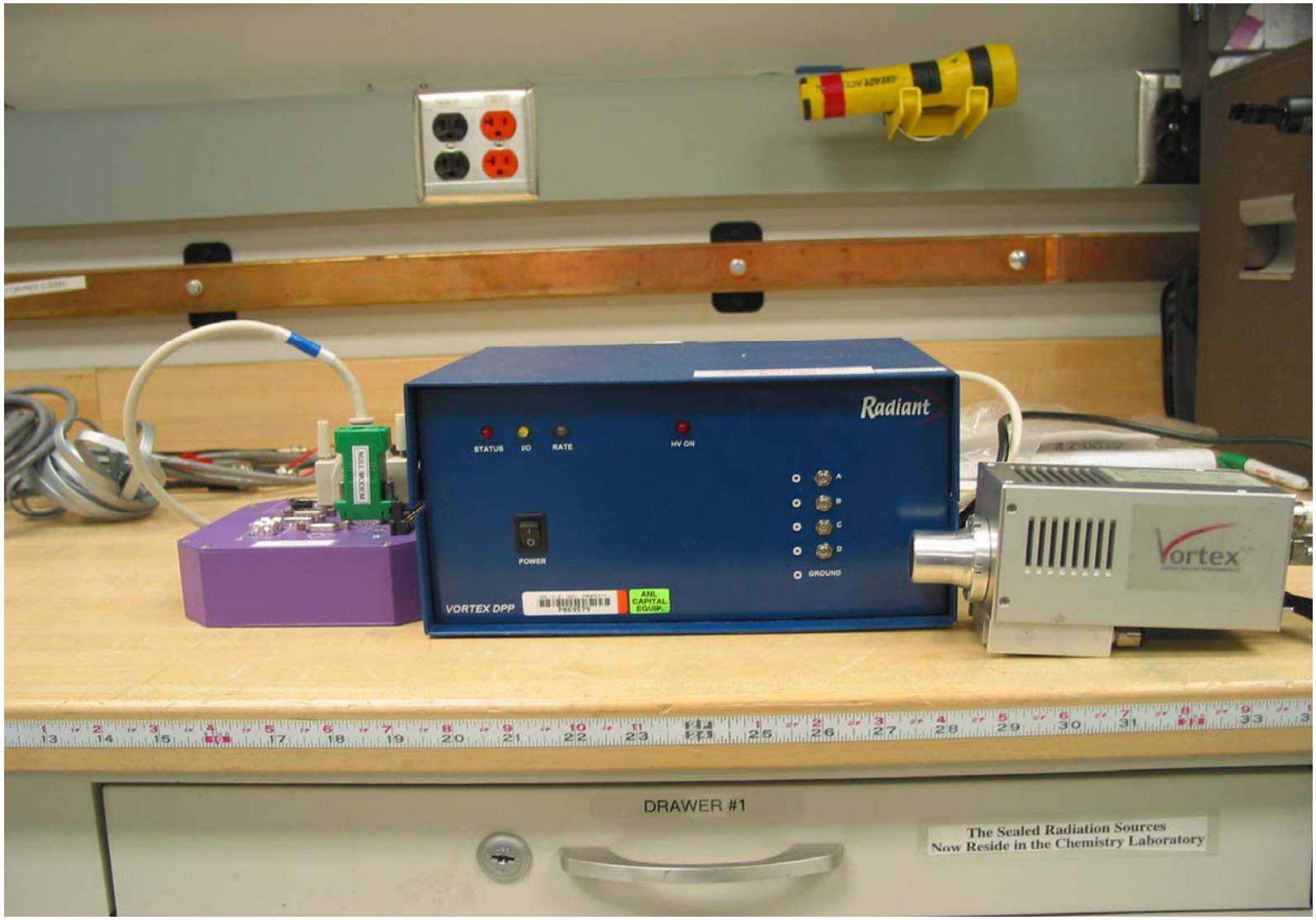
- DXP4C2X: CAMAC module for multi-element detectors. 4 detectors per CAMAC module. Obsolete, but still in use at some beamlines.
- Saturn: standalone unit for single-element detectors. This is also sold in an OEM version inside the Vortex electronics from SII
- xMAP: PXI module for multi-element detectors. 4 detectors per PXI module. Faster than Saturn and DXP2X, and with high-performance features.
- Mercury: New 4-channel module very similar to the xMAP, but in a standalone box like the Saturn with a USB 2.0 interface.


CANBERRA
16
element
detector
BRUKER AXS
VME
crate
CAMAC
crate
DXP4C
module
s

XIA Saturn


MAGNIFIER/ BRUSHES
MINI-WRENCHES & SOCKET
SCREWDRIVERS
STATUS
I/O
RATE
DIGITAL
XIA
GSECARS
001007
Spectrum Series
SATURN
POWER
DXP
X-RAY SPECTROMETER
DETECTOR BIAS CONTROL
ENABLE
ADJUST
V
RED WHEN ENABLED

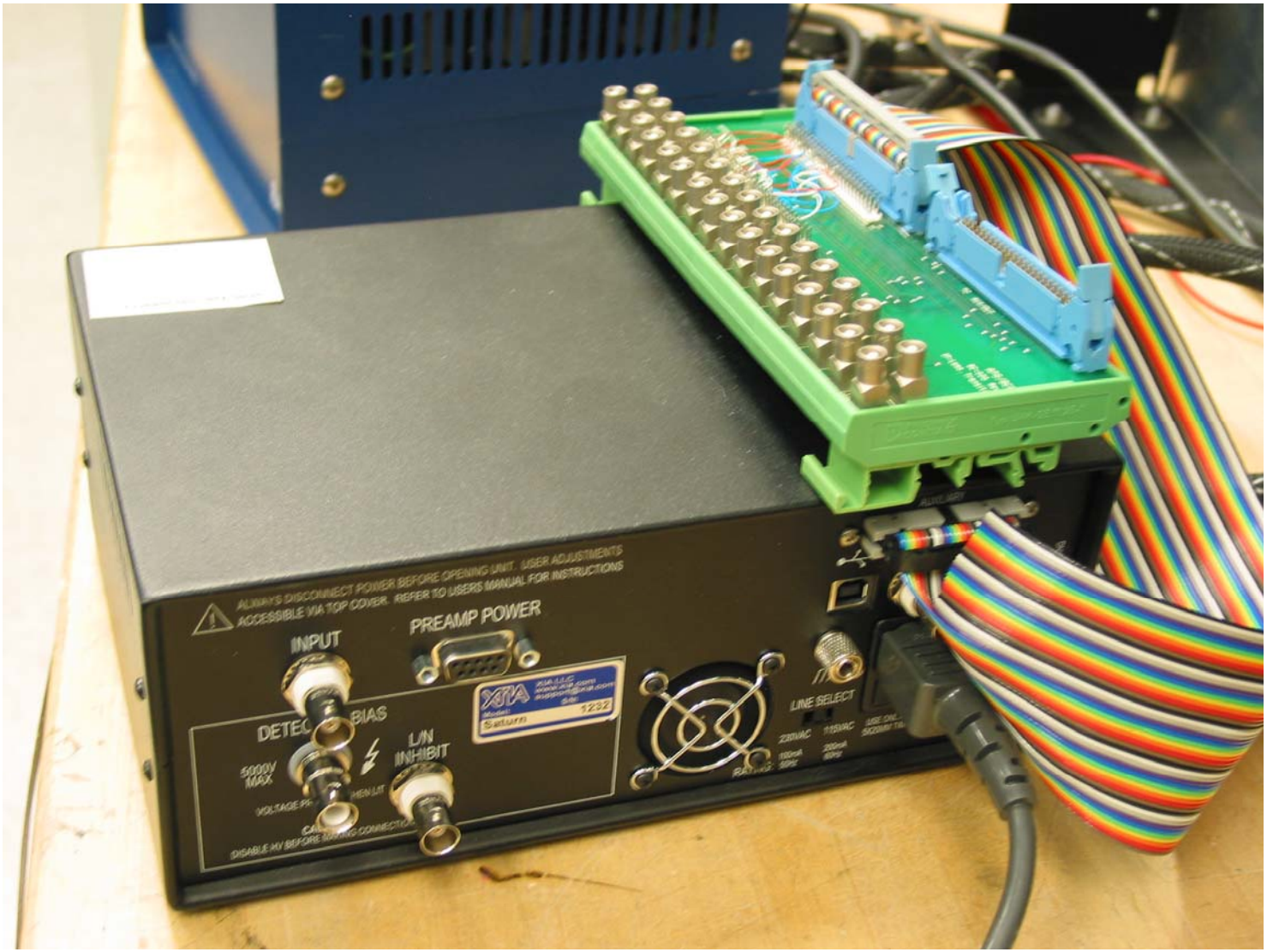
SII (formerly Radiant) Vortex detector and electronics
Saturn OEM version inside



Saturn electronics

- Older Saturns had parallel port (EPP) and USB 1.1 interface. Older Vortexes had EPP only.
- Newer Saturns and Vortexes have USB 2.0 only.
  - USB 2.0 is significantly faster than USB 1.1 and ~30% faster than EPP.
- Saturns available with an “ROI” option. When an x-ray within the energy window of the ROI is detected a pulse is output on 1 of 16 TTL output lines.
  - This allows very fast data collection, when used for example, with an SIS (Struck) multichannel scaler. 10 microsecond dwell times are possible.
- EPICS software propagates MCA record ROIs to the Saturn hardware ROIs.
- EPICS software runs on Linux and Windows for all 3 interfaces (EPP, USB 1.0, USB 2.0)

Saturn with TTL ROI outputs going to BCDA breakout panel



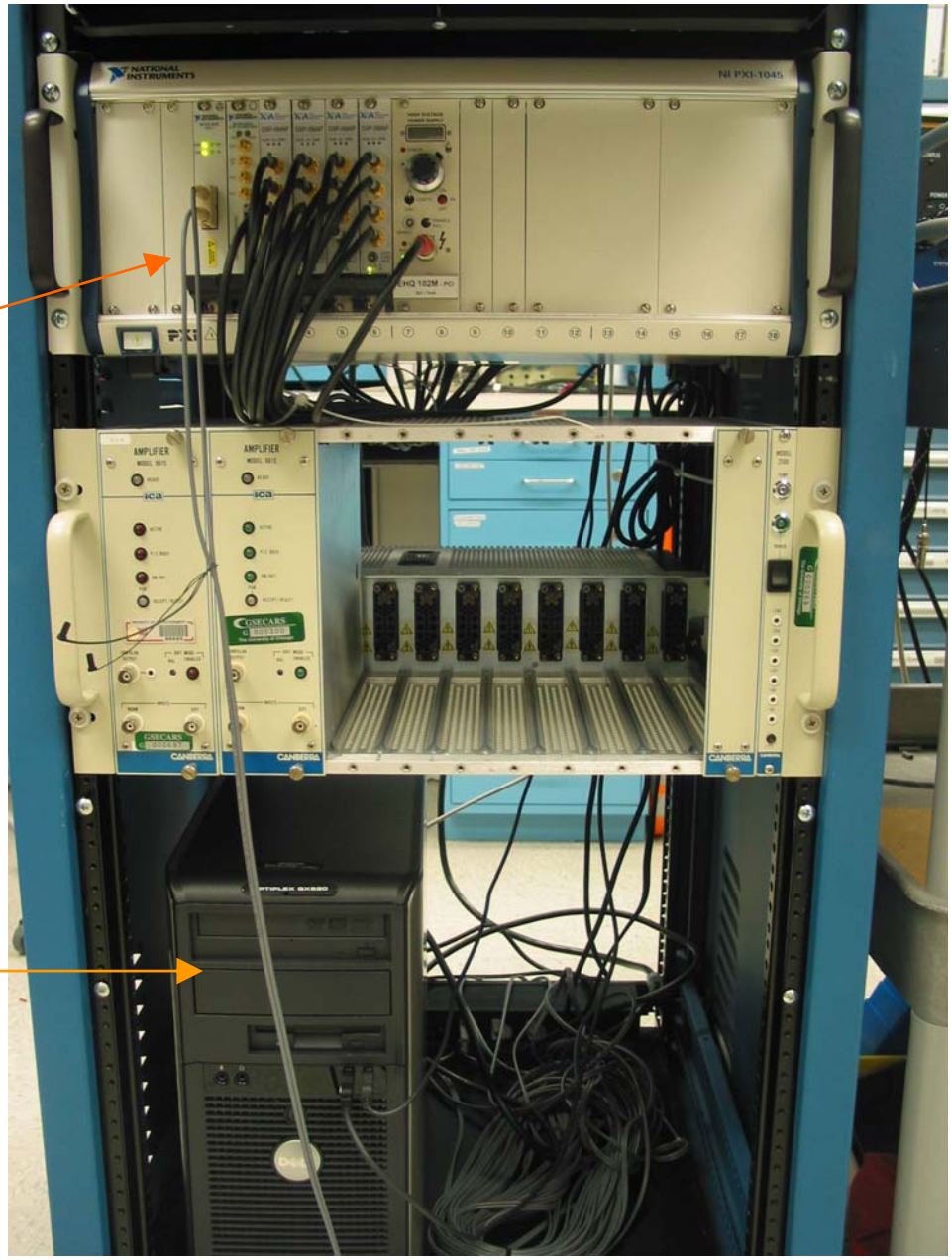
xMAP electronics

- 4 channels per module
- 4 MB of memory per module. Used to buffer spectra or ROIs for very data collection
- Double-buffered to support simultaneous readout and acquisition
- 1 LEMO input for gate and trigger functions.
- Peaking times down to 125ns
- Supports both RC and reset preamps
- PXI/PCI interface which acheives ~30 MB/sec when reading out xMAP. More than 30 times faster than CAMAC.

xMAP

PXI crate with 4 xMAP units (16 channels) and fiber PXI to PCI interface

Windows control computer



EPICS “dxp” module software
New features of Release 3-0

- Major rewrite
- Eliminate the special DXP record. Now all parameter control of the XIA electronics is done with standard EPICS records (ao, ai, bo, bi, etc.)
  - Single driver for parameter control and data acquisition
    - Driver is C++, derived from asynNDArrayDriver in areaDetector, which is derived from asynPortDriver in asyn
  - Still uses MCA record for simple data acquisition
  - Simpler, easier to maintain.
  - More features available

EPICS “dxp” module software
New features of Release 3-0

- Previously the DXP record had to be processed to get ICR and OCR for accurate live time correction
- ICR, OCR and trigger counts and output counts are now always updated when the spectrum is read.
- Trigger live time and energy live time now both available

Saturn features in Release 3-0

- Correct live time. Previously the live time of the trigger filter was reported. Now it is the correct energy-filter live time.
  - No need to collect ICR/OCR to compute correct live time any more.
- Saturn firmware is included to use the ROI TTL output feature if the Saturn is equipped with that option. Very fast mapping with ROI counts (not full spectra).
- Performance: ~40 spectra/second with .01 sec acquire time, USB 2.0 interface on Windows, saving 2048 channel full spectra to disk
- Many thousands of ROIs/second using TTL outputs to SIS multichannel scaler

xMAP Mapping Modes in Release 3-0

- MCA mapping
  - Spectra are buffered into onboard 4MB of memory
  - Double buffered for simultaneous readout and acquisition
  - With 2048 channel spectra each buffer holds 124 pixels maximum.
  - Performance: Limited by readout rate of xMAP over PXI/PCI, ~4,000 2048 channel spectra per second. For a 4-channel system (e.g. quad Vortex) this is 1,000 pixels/second. For a 100-element EXAFS detector it is 40 points/second
  - The first pixel in each buffer is sent to the MCA records for visual feedback on the data.
    - The buffer size can be decreased from 124 pixels when mapping slowly to get more rapid feedback.

xMAP Mapping Modes in Release 3-0

- ROI (SCA) mapping
  - Total counts in up to 16 ROIs per detector are collected into onboard 4MB of memory
  - Double buffered for simultaneous readout and acquisition
  - With 16 ROIs each buffer holds 5457 pixels maximum
  - Performance: Limited by xMAP overhead in pixel advance to about 100 microseconds/pixel, i.e. 10,000 pixels/second.
  - For a 16-element detector with 16 ROIs/detector this is 2.5M ROIs/second.

xMAP Mapping Modes in Release 3-0

- Pixel advance sources:
  - Software: This is a PV that can be written to at any time
  - External trigger: Trigger input to LEMO connector.
  - External sync: Like external trigger, but with option to divide input by N. Can be used to divide stepper motor pulses, for example, to have each pixel be 25 motor steps.

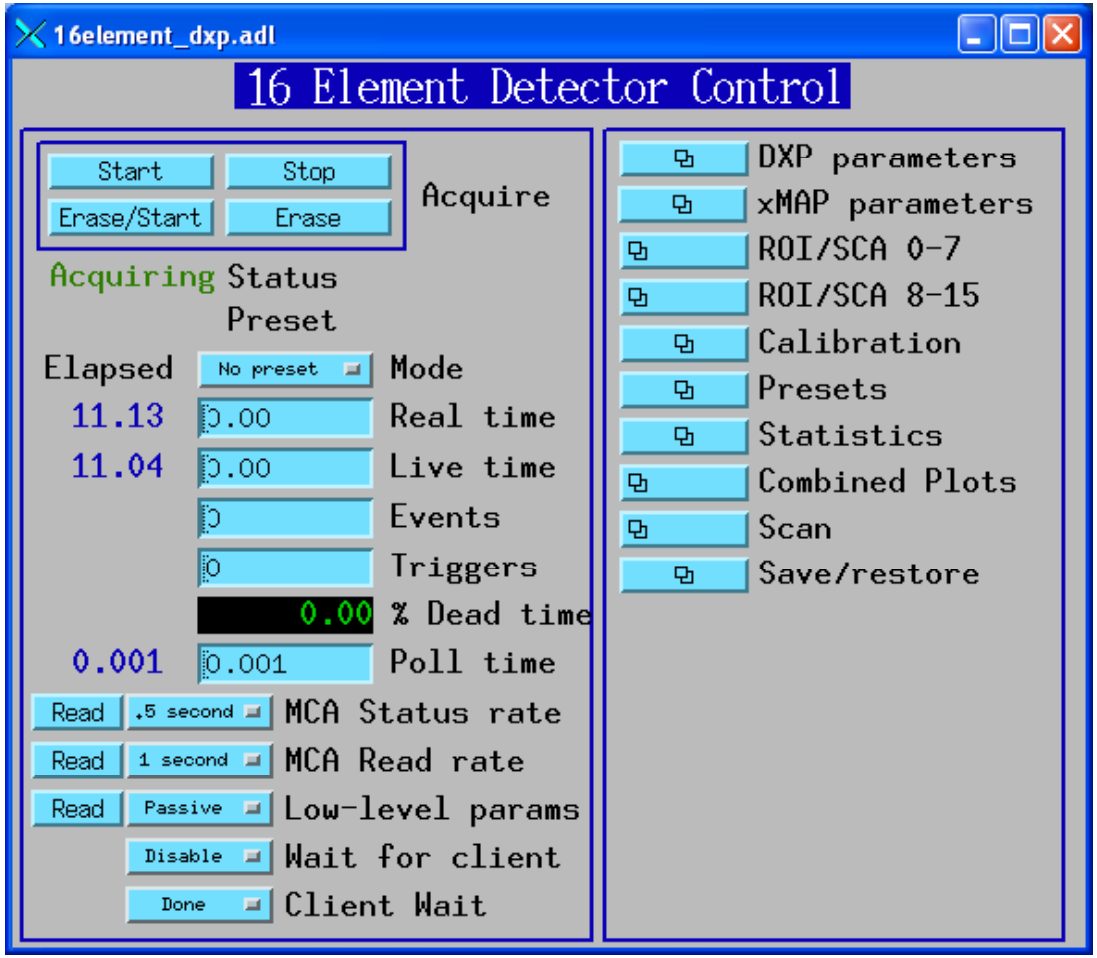
xMAP Mapping Modes in Release 3-0

- Data acquisition
  - When buffer fills up the EPICS software automatically reads it out and calls any NDArray plugins (from the areaDetector module) that have registered for callbacks.
  - The data are 16-bit 2-D arrays, 1047808 x N_modules.
    - The data in each array is a buffer containing the spectral data, as well as live time, real time, input counts and output counts.
  - The plugins will normally be file-saving plugins. The netCDF, TIFF and NeXus/HDF plugins from areaDetector can all be directly used. The JPEG plugin will not be useful!
  - The netCDF plugin can stream data continuously to a single netCDF file. The TIFF plugin writes each 2-D array to a separate TIFF file
  - IDL and Python routines are available to extract the data from the netCDF files.
  - Continuously streaming data at the rates on the previous slide

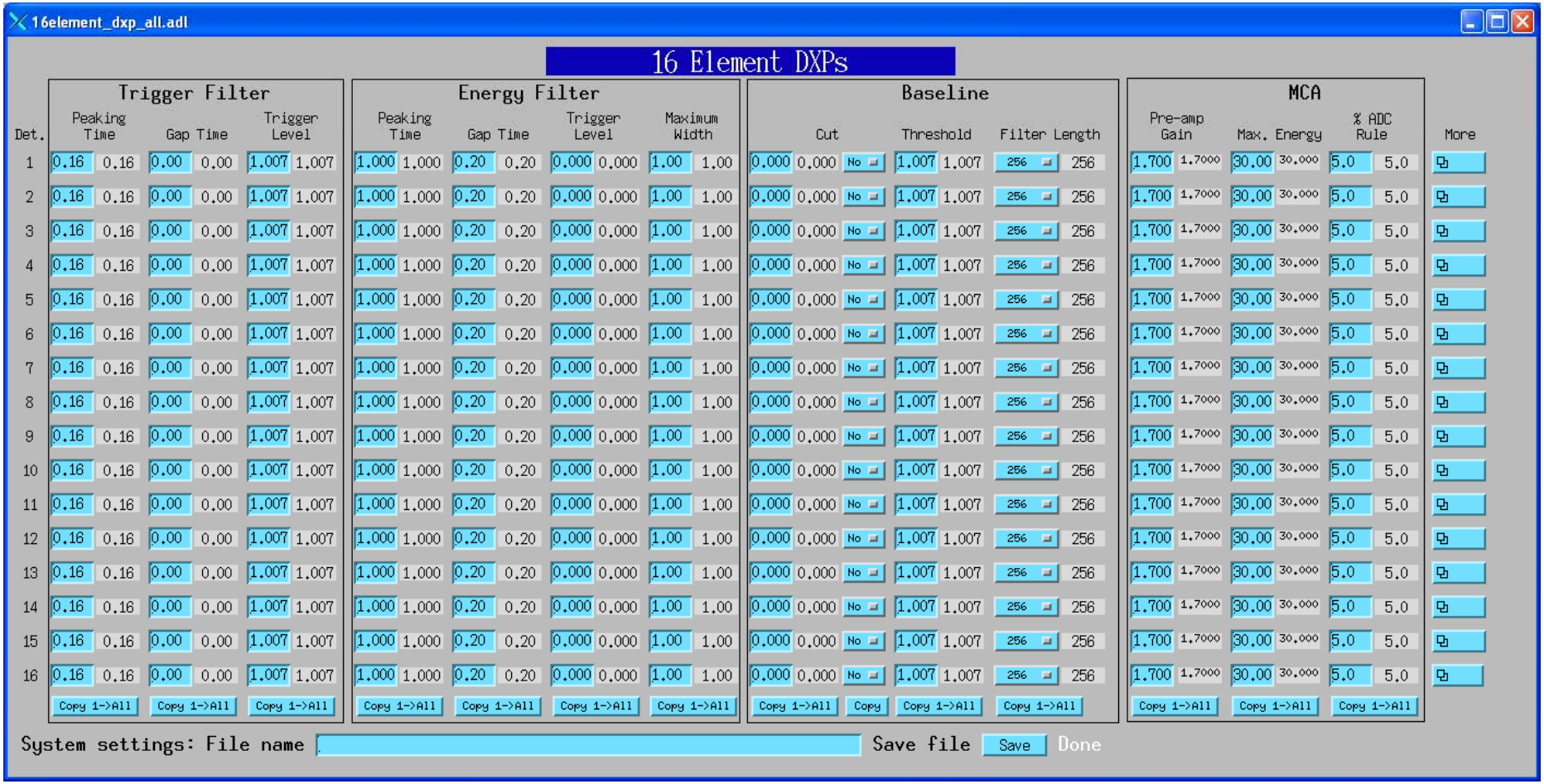
Other multi-element features in Release 3-0

- More preset modes with xMAP: None, real time, live time, triggers, events (total counts).
- Time to start up xMAP at EPICS iocInit reduced from >3 minutes to <30 seconds for 16 channel detector system.
- Time to copy ROIs to SCAs reduced from >1 minute to 1 second.
- Copy DSP parameters from detector 1 to all detectors
- Copy ROIs from detector 1 to all detectors, by channel or by energy
- Copy ROIs (MCA record) to SCAs (XIA hardware) for all detectors for all ROIs.
- Several additional diagnostic trace plots

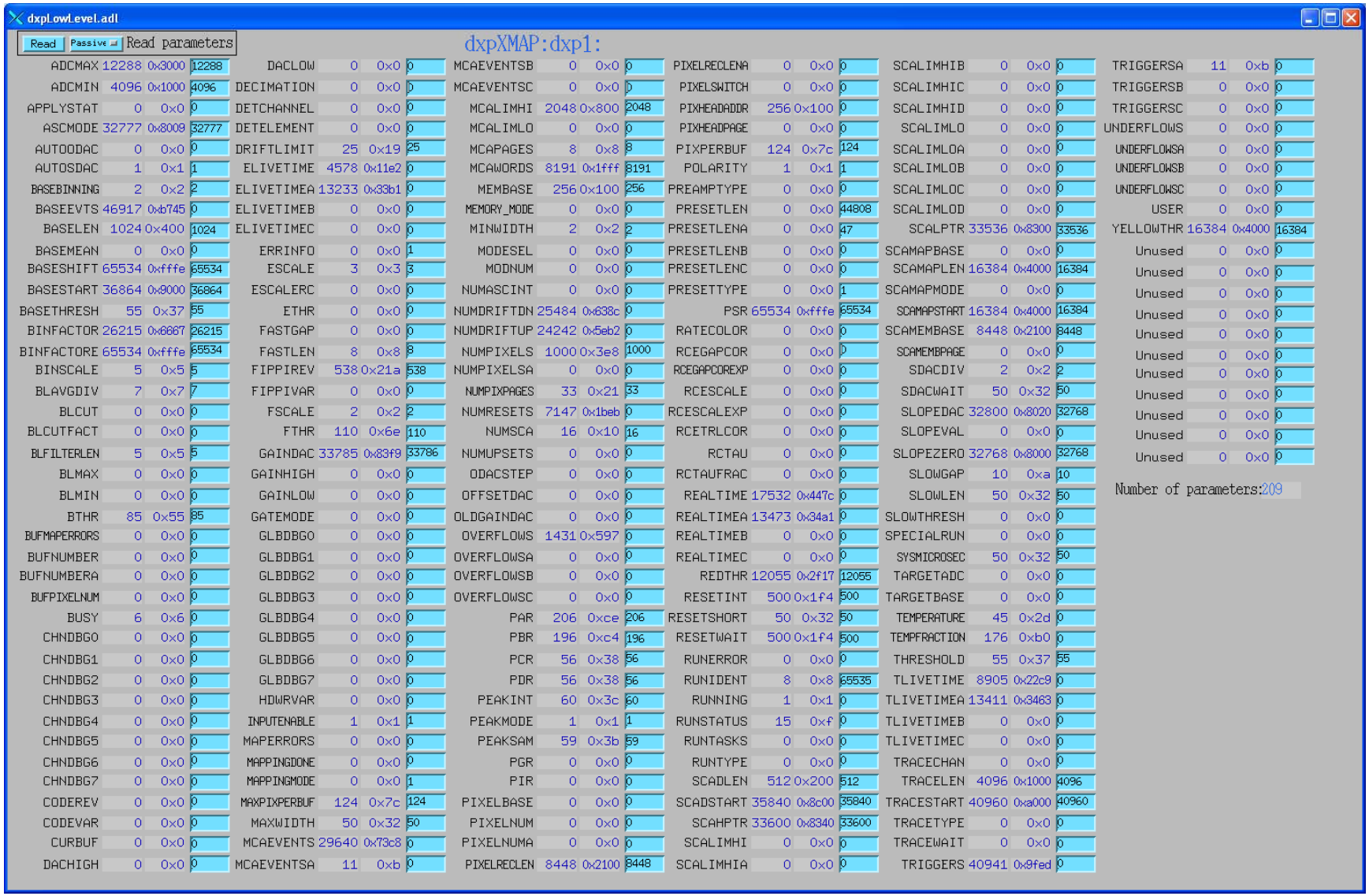
16 element top-level medm screen



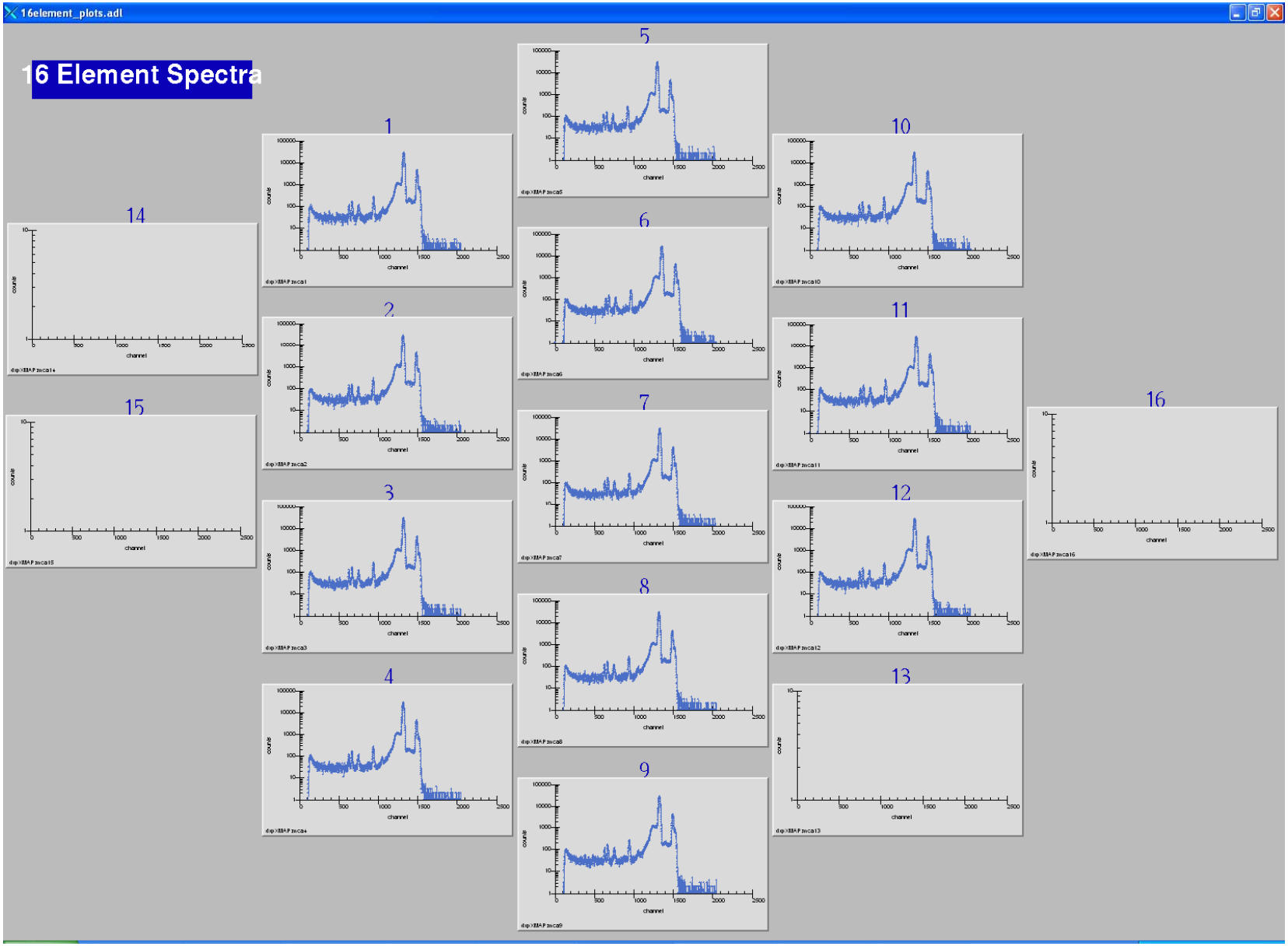
16 element high level parameters



Single channel low-level parameters



16 element combined spectra



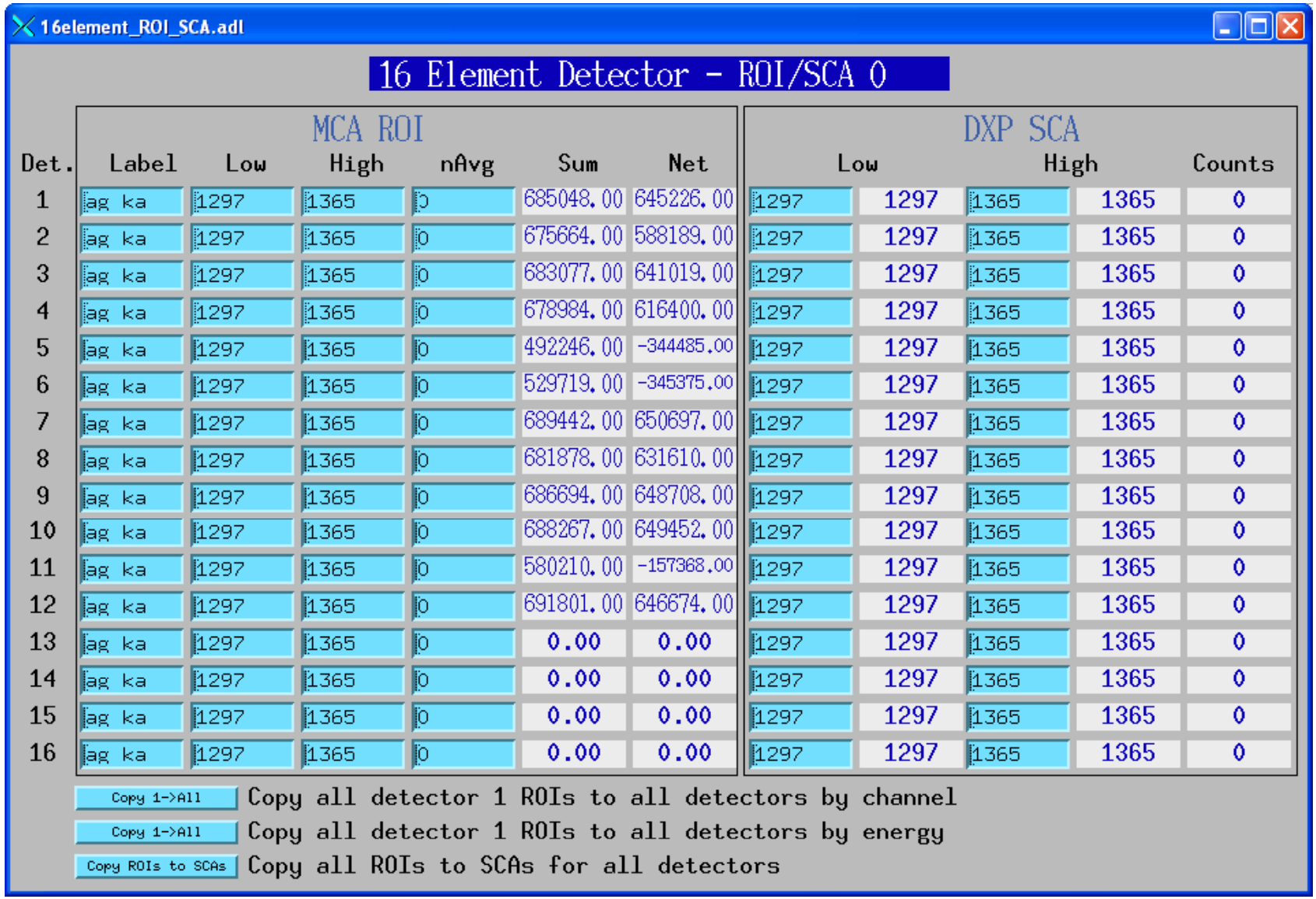
16 element statistics

16element_dxp_statistics.adl

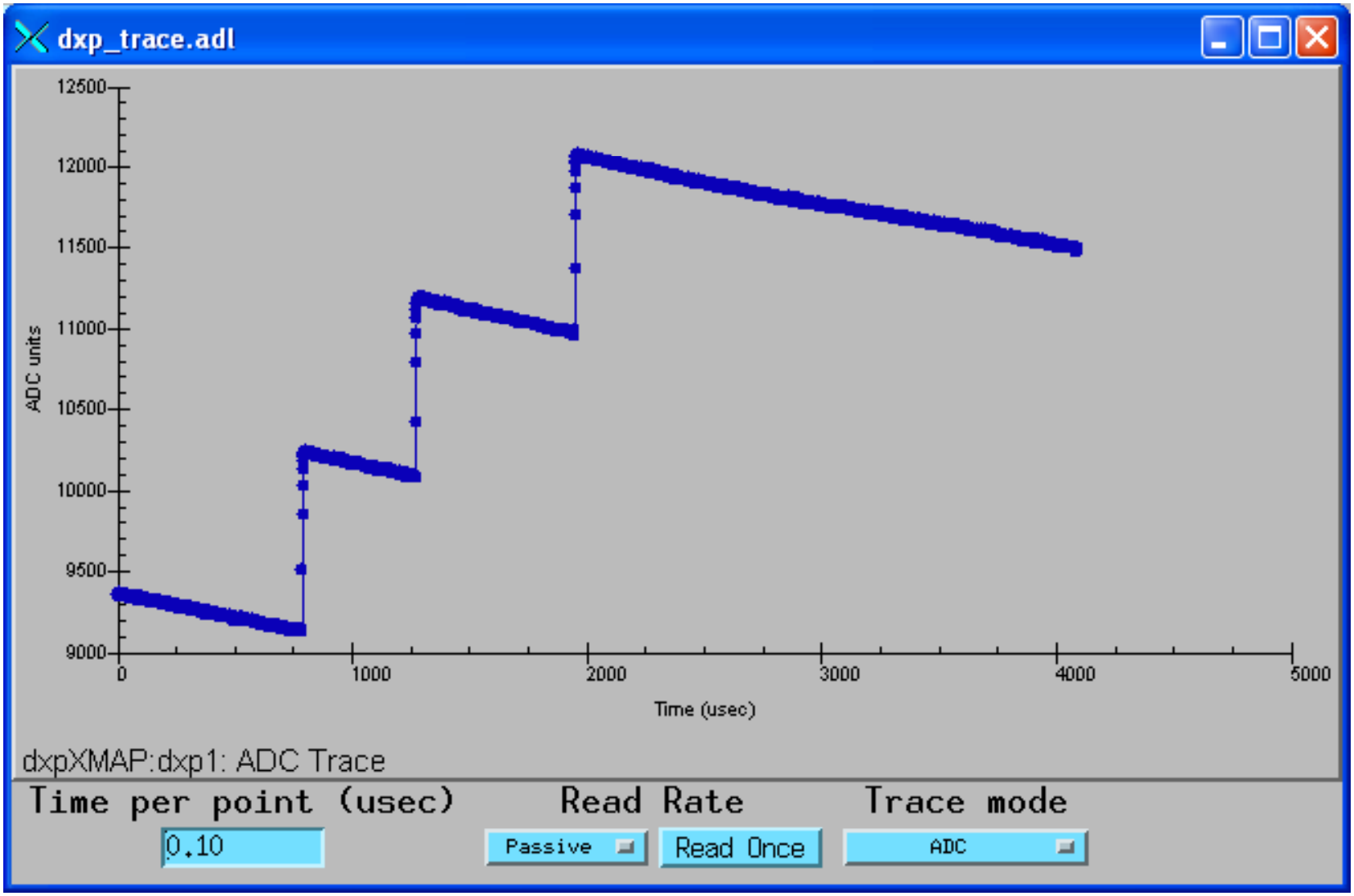
16 Element Detector Statistics

Det.	Elapsed Real	Elapsed Live	Trigger Live	Elapsed Triggers	Elapsed Events	ICR	OCR	Acquire Status	Dead Time
1	348.40	342.29	346.781	967126	952793	2788.9	2740.0	Done	1.75
2	348.40	342.28	346.787	967065	952674	2788.6	2739.6	Done	1.76
3	348.40	342.27	346.781	967086	952710	2788.7	2739.7	Done	1.76
4	348.38	342.29	346.788	967129	952773	2788.8	2740.1	Done	1.75
5	358.35	352.12	356.719	967406	953126	2712.0	2664.9	Done	0.00
6	358.34	352.10	356.647	967953	953787	2714.0	2666.8	Done	0.00
7	358.35	352.04	356.679	967846	953449	2713.5	2665.8	Done	0.00
8	358.34	352.13	356.691	967670	953463	2712.9	2665.8	Done	0.00
9	358.37	352.13	356.718	967736	953487	2712.9	2665.7	Done	0.00
10	358.37	352.19	356.715	967795	953670	2713.1	2666.2	Done	0.00
11	358.37	352.18	356.687	967950	953883	2713.7	2666.8	Done	0.00
12	358.37	352.21	356.713	967878	953824	2713.3	2666.7	Done	0.00
13	358.40	358.39	358.394	0	0	0.0	0.0	Done	0.00
14	358.40	358.35	358.351	0	0	0.0	0.0	Done	0.00
15	358.40	358.36	358.357	0	0	0.0	0.0	Done	0.00
16	358.40	358.35	358.349	0	0	0.0	0.0	Done	0.00

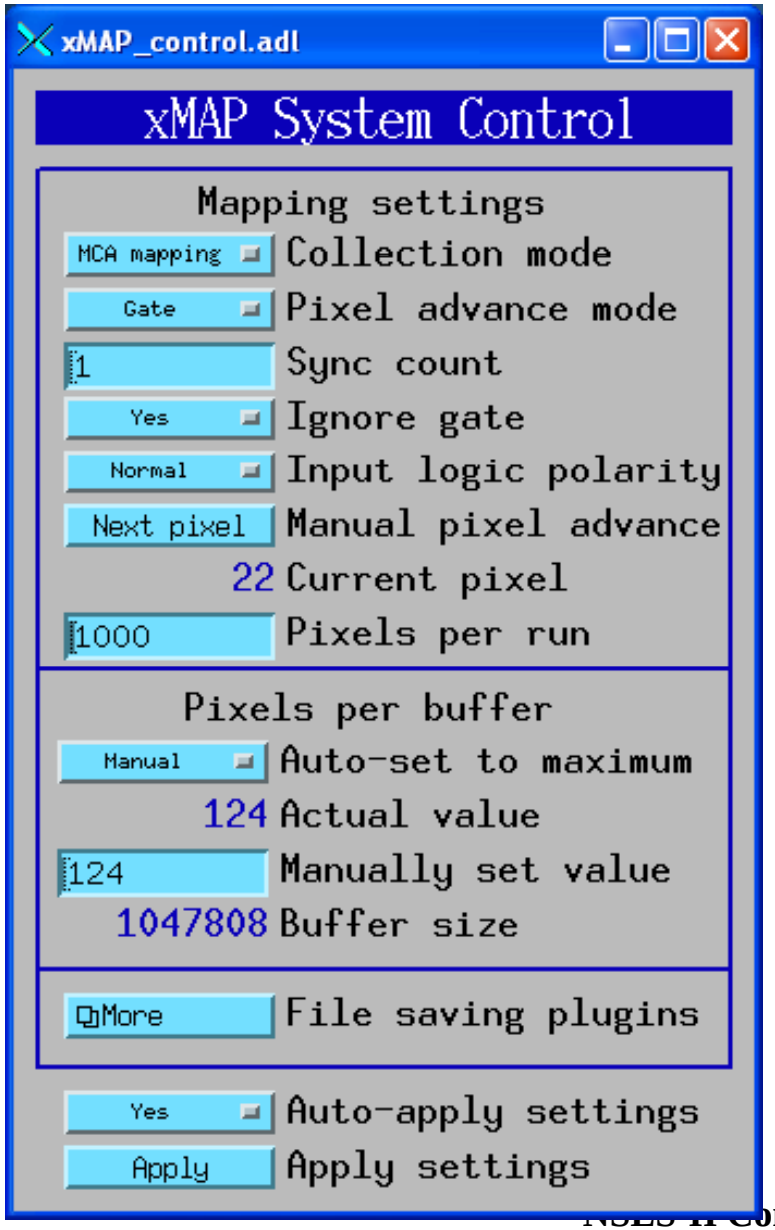
16 element ROIs and SCAs



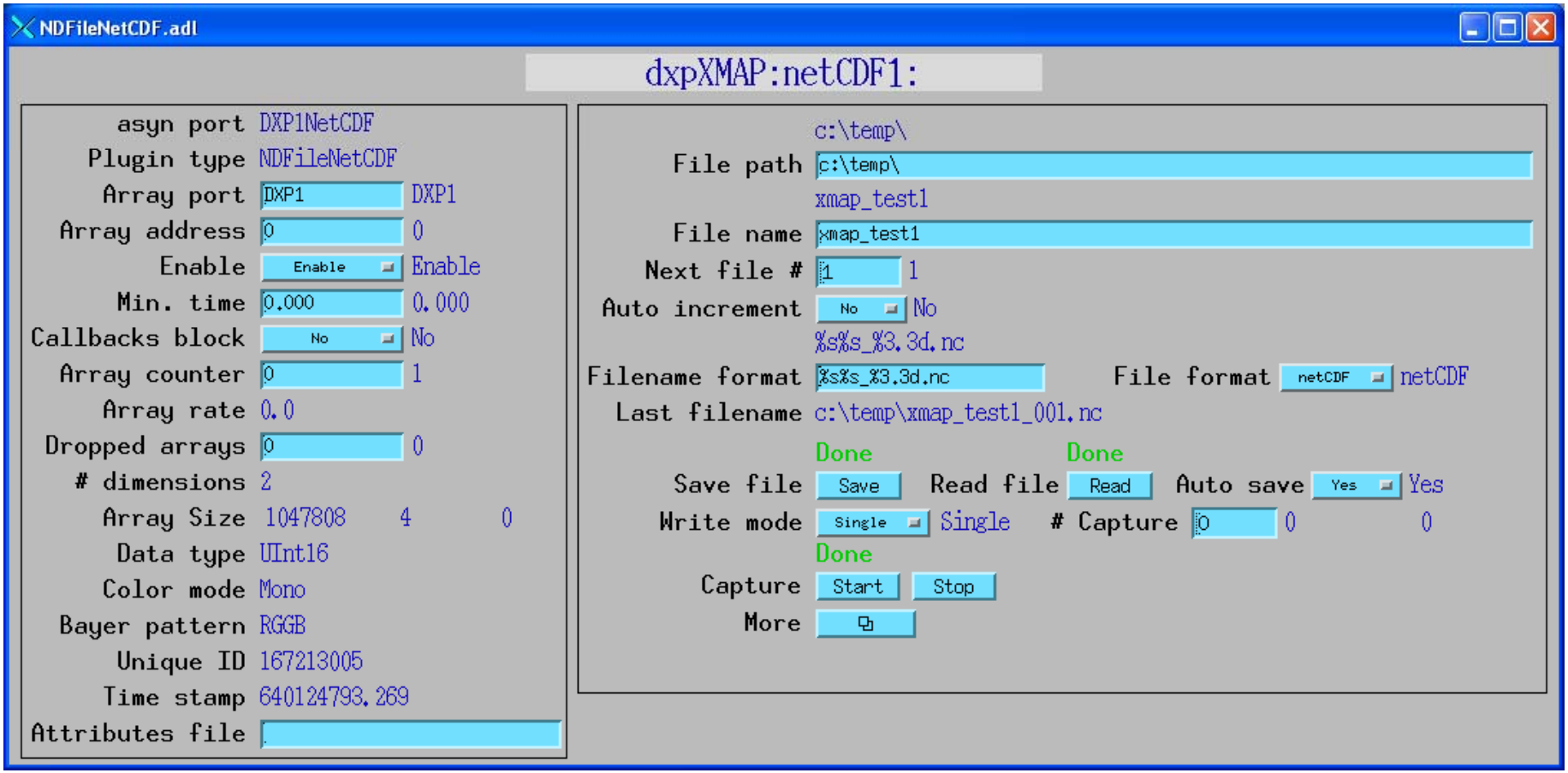
Single channel diagnostic trace of pre-amp input using xMAP like a digital scope



xMAP mapping mode setup



netCDF file saving plugin for mapping modes

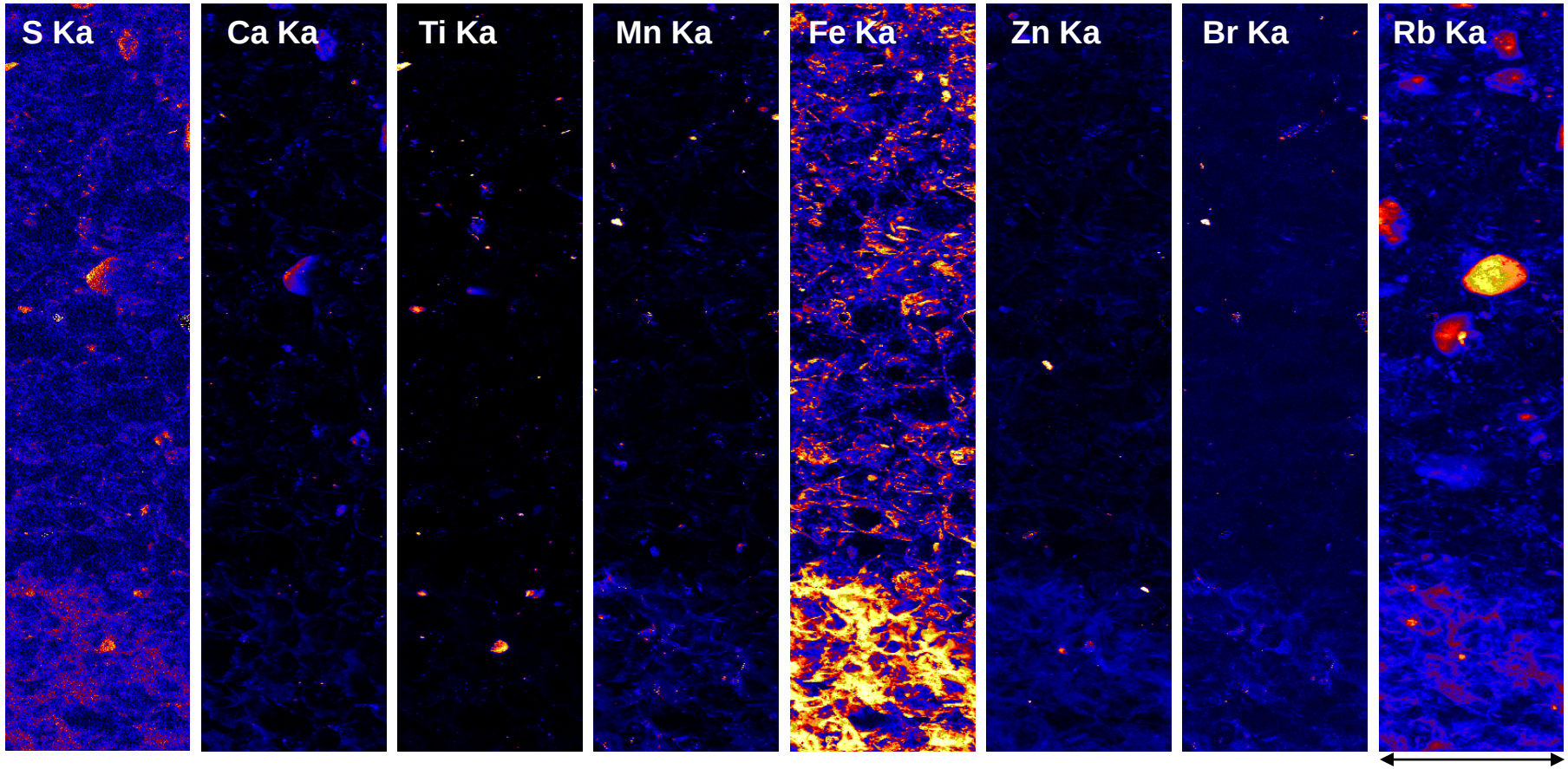


First Results with xMAP MCA Mapping Mode
Matt Newville, 13-ID-C

- SII quad Vortex detector
- Sample stage driven with Newport XPS motor controller running trajectory scanning software, continuous stage motion
- Bi-directional stage motion
- XPS puts out a trigger pulse at each pixel
- XPS captures actual stage position when each trigger pulse is output
- Trigger pulse goes to channel advance on SIS multichannel scaler to capture I0 from ion chamber & V/F converter
- SIS output pulse triggers xMAP trigger input
- Current version of software collects 1 row of image in xMAP buffer and writes to netCDF file
  - Could do an entire image into a single file to lower overhead.
  - Need to see if another process can read the file for display update
- Python software reads file, converts to an older format that can be displayed by Matt's Python collection software.
  - Adds additional overhead, but will be replaced with a new system Matt is designing

XRF Fast Mapping Mode example 1

G. Morin, F. Juillot Univ Paris VI



Maps of XRF intensity in sediment sampled near zinc smelter.

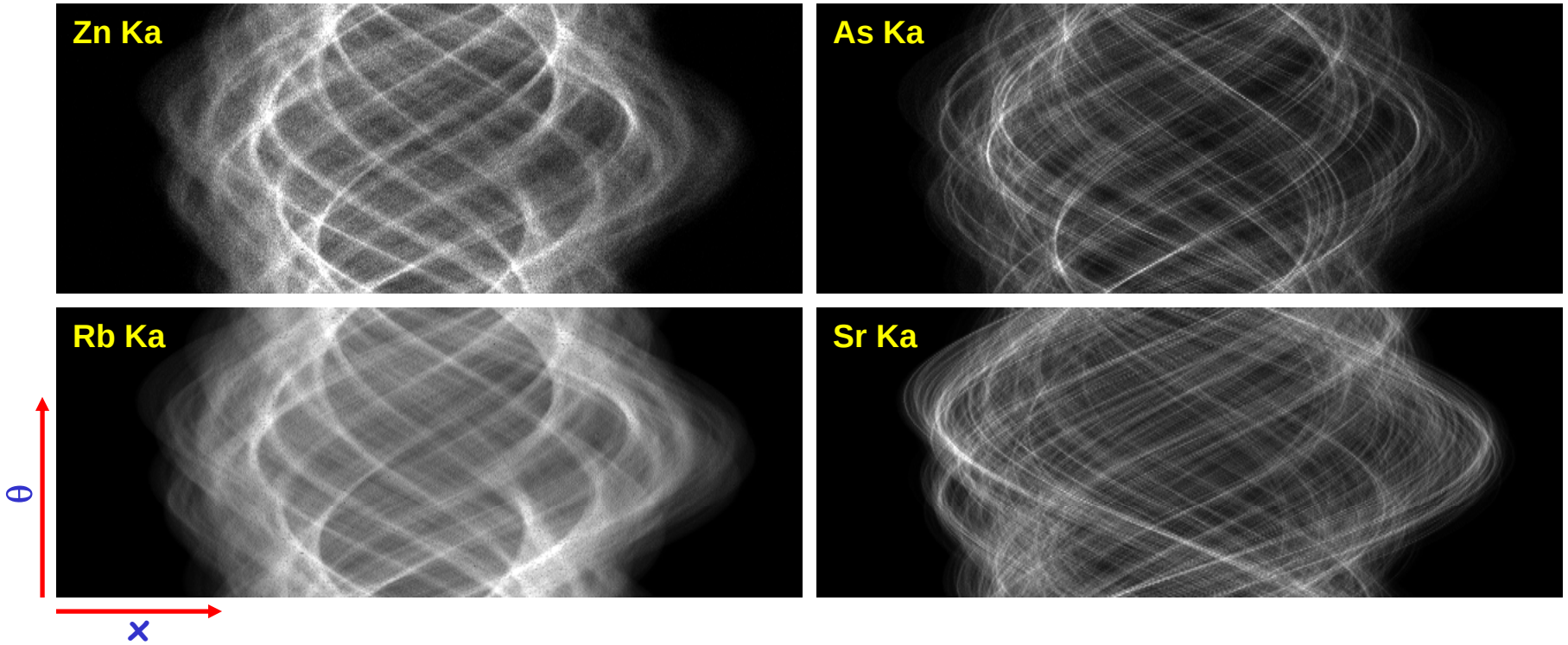
Data collection: 201 x 801 pixels (pixel: 5μm x 5μm) collected at 25ms per pixel

Time per Row = 5.025sec collection + ~2 sec overhead per line
Total Time = 1:37:10 (would be 1:13:47 if done as 801 x 201!!)

At 0.5sec per pixel (previous max rate), total collection time would be 22:21:41

XRF Fast Mapping Mode example 2: Fluorescence Tomography

Anne-Marie Carey, U. of Aberdeen, Kirk Scheckel US-EPA:
Distribution of Heavy Metals, especially As, in Rice



X-θ maps of XRF intensity in panicle (small stem to grain) in rice, grown in As(III)-spiked solution

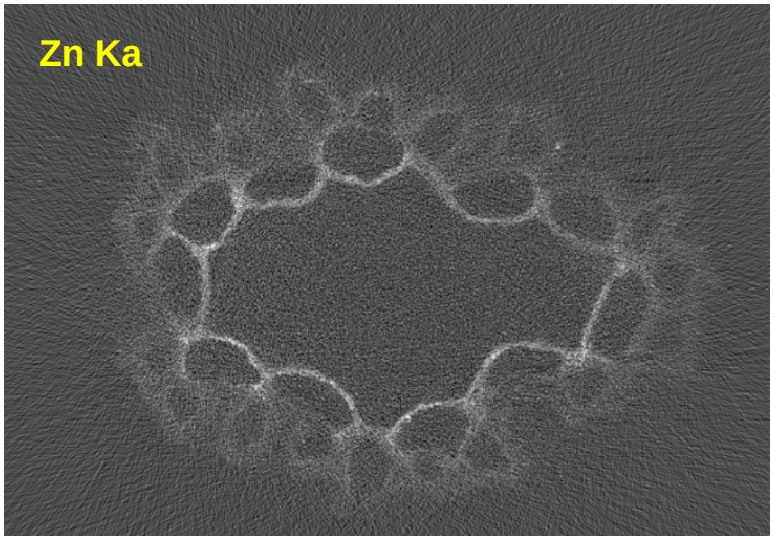
Data collection: 648 x 181 pixels (pixel: 2μm x 1degree) collected at 30ms per pixel

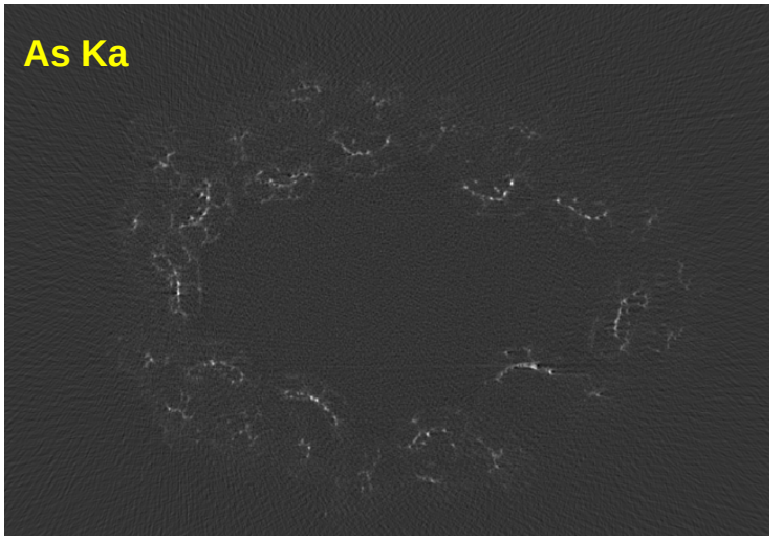
Time per Row = 20.5sec collection + ~2 sec overhead per line
Total Time = 1:07:20

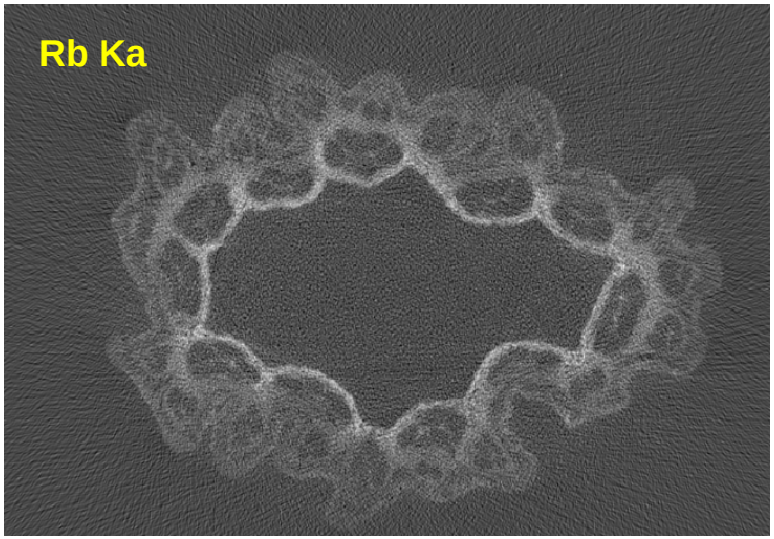
At 0.5sec per pixel, total collection time would be 17:11:42

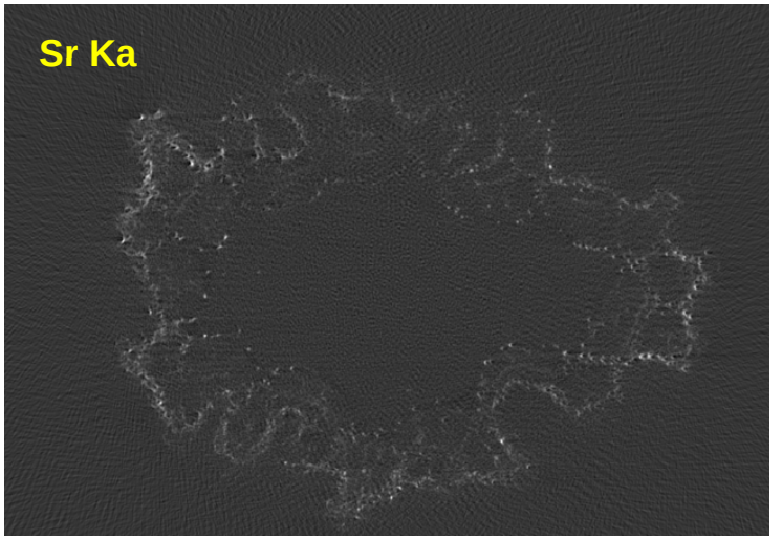
XRF Fast Mapping Mode example 2: Reconstructed Slices

Anne-Marie Carey, U. of Aberdeen, Kirk Scheckel US-EPA









Rb: marks phloem transport

Sr: marks xylem transport